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MECHANICAL DESIGN OF AN OMNI-DIRECTIONAL SENSOR MOUNT

Ross-Hime Designs, Incorporated

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13. ABSTRACT (Maximum 200 Words)
This effort has been directed to development and demonstration of a gimbal mount capable of 180 degree singularity-free pitch and yaw motion about a two-axis center, avoiding the common problem of gimbal lock. In phase I, design of the model was completed.
This report documents the transformation of the design to a fully functional device, meeting the design goals (not just the minimum acceptable performance) for a gimbal suitable for use as a mount in a satellite communication link. The gimbal has been installed in the AFRL Satellite Communication Testbed located in the Watson Laboratory of SUNY Binghamton; it will be available for remote experimentation through the NSF established internet capability at the University.

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1   Introduction

The primary purpose of this Contract with Air Force Research Labs/Ballistic Missile Defense Organization was to further develop the low cost, easy to manufacture, highly accurate Sensor Mount (aka: Omni-Wrist III) that Mark Rosheim designed in his Phase I Antennae Pointer project, and to manufacture and test one prototype unit for delivery to AFRL/BMDO.

For over 50 years, designers have built sensor mounts for various civil and military applications using variations of a rotary base for azimuth positioning, along with a fork or clevis device to provide declination positioning. A primary weakness in these designs occurs when the sensor is pointed straight up (Azimuth 0 degrees and Declination 0 degrees). At this location these designs suffer from singularity or "gimbal lock". Additional problems associated with these designs involve high manufacturing and maintenance costs, complicated kinematics, bulky and inflexible wiring harnesses, large cross-sections and mass-moments of inertia (resulting in high electrical power requirements), and packaging for harsh environments.

The technology created by Ross-Hime Designs results in a break-through solution to these issues. The Omni-Wrist III features a unique mechanical design that eliminates any singularity or gimbal-lock issue. In witness to the unique mechanical design, during the design process, using "Solid Works" software, we encountered a problem with generating a virtual motion picture of the design. The software did not recognize the kintmatic nature of the device, and viewed it as a static linkage with no motion capability. A visit to the Twin Cities by a representative of Solid Works soon resulted in a new revision to their software.

Its small parts count and use of commercial components addresses the issues of manufacturing cost and maintenance. 2 different individuals easily calculated the kinematics solution in a short period of hours. The thru-the-center hole design allows all wiring and hoses to pass through the center of the Omni-Wrist, eliminating the need for special shrouding and protection. It is compact and low inertia compared to other designs, and it would be a simple matter to shroud the entire device.

1.1   The stated Design Specifications were:

Payload Capability: 5 lbs.

Range of Motion: 180 degree Hemisphere

Output Speed: 60 degrees/sec

Accuracy: .06 Degree = 3.6 arcminutes = 216 arcseconds

Physical Envelope: Cylindrical, 10" diameter x 18" long

Weight of Sensor Mount: 20 lbs.

These Specifications were stated as goals and were based on the characteristics of the Phase I design. As witnessed during a recent visit to our offices by Professor Don Nicholson, our efforts did result in a prototype that meets or exceeds each of these design goals.

There are two items to be corrected that we discussed with Professor Nicholson at that meeting. First is an occasional, random failure to properly execute the HOME command. The wrist will run through the HOME routine and end that routine in a position approximately 18 degrees declination by 180 degrees azimuth instead of the proper "0 x 0" home. The second item is the ability to enter a negative declination number into the GUI. Mr. Conrad Wilson, of Oceaneering Space Systems, has corrected both of these items in the source code. However the program was received after we shipped the Sensor Mount to Rome, NY. The software code is being emailed to Rome and a copy is included on a floppy disc found in the 3-ring binder.

1.2   The actual test results are included in two parts.

First, we include a copy of the CMM testing data developed by our Controller Partner, Oceaneering Space Systems of Houston, Texas. Mr. Conrad Wilson of OSS produced this data. Conrad was also the developer of the software code, as well as the controller hardware. Should any changes of the parameters such as velocity, acceleration, the PID values, etc. be required, please contact Mr. Wilson. He is most helpful and capable.

Second, we include a copy of the test results generated by our own Dr. Gerald Sauter. Both of these sets of data speak for themselves, and the reports include appropriate summaries and conclusions.

1.3   In general terms, our results are:

Payload Capacity: All testing was done with a simulated payload with a weight of 5.2 lbs. We also experimented with payloads as heavy as 10 lbs with similar results. It is noted that as the weight is increased, there is some deflection of the mechanism. Further study would be study two areas: determining the amount of deflection per pound of weight, and re-designing the geometry of the arms to stiffen them. We have a current project for a potential customer with a payload specification that exceeds 5 lbs.

Range of Motion: The device exceeds the stated goal of 180 degrees of capacity. There are magnetic limit switches located in a position to limit the range of motion to something less than 181 degrees but more than 180 degrees. The software includes the provision to not accept any command that would cause the declination to exceed 90 degrees, and it will not accept a manual declination command larger than 90.000 degrees.

Output Speed: The speed is currently set at approximately 60 degrees per second. There is a provision in the software code to raise or lower the output speed. Conrad Wilson can assist you in accessing this parameter if you wish. The velocity can also be lowered only via the GUI as outlined in the manual.

Accuracy: As detailed in the accompanying two reports, the goal of 216 arcseconds was met and exceeded. In general terms the accuracy is around 70 arcseconds, and is very repeatable.

Physical Envelope: The wrist portion of the mechanism is basically a sphere of less than 10" diameter. The height, not including the base is less than 18" in height. The major factor affecting the height is the height of the Exlar Linear Actuators. These actuators are the smallest commercially available linear actuators that meet the linear accuracy and repeatability required.

Weight of Positioner: The weight is less than 20 lbs.

2   Included Information

In addition to this report, we also include the following items:

One copy of each of the test reports.
One set of mechanical drawings.
One set of software documents and instructions.
Exlar manual and catalog.
AMC motion controller manual and catalog.
3 wiring harnesses for adding a VGA monitor, keyboard, and a Iomega Zip drive to the controller CPU.
A floppy disc containing the latest revision of the software code mentioned above.
A CD-ROM of the virtual motion picture video.
Additional floppy discs containing this report.

3   Conclusion

Conrad has, from time to time, made several suggestions for refinements to the basic controller provided with the prototype. Among the best suggestions he offered are additional memory and processing code to enable the development of a predetermined, non-linear path, as well as a path storage module to enable the controller to remember any motion and repeat it at will (much the same as the "HOME" routine). We hope that AFRL/BMDO will consider a follow-on contract with Ross-Hime Designs to develop these and possibly other refinements.

Appendix A
Test Results at Oceaneering Space Systems, Inc. (OSS)

To date we have received test data from Oceaneering Space Systems, Inc. (OSS) but no written report. The description that follows is based on that data along with conversations with the test personnel.

Figure A1: Sensor Mount Attached to CMM at OSS

A Coordinated Measuring Machine (CMM) was used to determine the accuracy of pointing for the Sensor Mount. The CMM is capable of high precision measurements of any point on the Sensor Mount. Figure A1 shows the Sensor Mount attached to the CMM at OSS. From conversations with OSS personnel, the tip of the Sensor Mount was used for these measurements. As the Sensor Mount was exercised the position of the tip was precisely determined. These positions were then compared with expected values and the various errors were calculated. We understand that the Sensor Mount was placed within the CMM and

exercised at two azimuth settings, (0 and 45 degrees). At each of these positions the declination angle was changed from 0 to 81 degrees in several steps. All told there were 58 separate positions.

Table A1 Set of Data Points Used for CMM Measurements

Data #	Azimuth	Declination	Data #	Azimuth	Declination
1	0.000	0.000	30	45.000	0.000
2	0.000	10.000	31	45.000	10.000
3	0.000	11.000	32	45.000	11.000
4	0.000	20.000	33	45.000	20.000
5	0.000	21.000	34	45.000	21.000
6	0.000	30.000	35	45.000	40.000
7	0.000	41.000	36	45.000	41.000
8	0.000	60.000	37	45.000	60.000
9	0.000	61.000	38	45.000	61.000
10	0.000	70.000	39	45.000	70.000
11	0.000	71.000	40	45.000	71.000
12	0.000	80.000	41	45.000	80.000
13	0.000	81.000	42	45.000	81.000
14	0.000	-10.000	43	45.000	-10.000
15	0.000	-11.000	44	45.000	-11.000
16	0.000	-20.000	45	45.000	-20.000
17	0.000	-21.000	46	45.000	-21.000
18	0.000	-30.000	47	45.000	-30.000
19	0.000	-31.000	48	45.000	-31.000
20	0.000	-40.000	49	45.000	-40.000
21	0.000	-41.000	50	45.000	-41.000
22	0.000	-50.000	51	45.000	-50.000
23	0.000	-51.000	52	45.000	-51.000
24	0.000	-60.000	53	45.000	-60.000
25	0.000	-61.000	54	45.000	-61.000
26	0.000	-70.000	55	45.000	-70.000
27	0.000	-71.000	56	45.000	-71.000
28	0.000	-80.000	57	45.000	-80.000
29	0.000	-81.000	58	45.000	-81.000
				0.000	0.000

Initial Test Results

Table A1 is a list of the angles used in these measurements. The tests involved a Commanded Az. and Dec. angle followed by movement to these angles. The actual Az. and Dec. angles were measured by the CMM. Errors were determined and plotted. The next several graphs show these results.

Figure A2 displays the difference between the commanded position and the CMM measured position for azimuth and declination. The units for both the X and Y axis are degrees.

Figure A3 shows several azimuth error measurements. The commanded vs GUI reported error, the commanded vs CMM measured error and the GUI reported vs the CMM measured error.

ERRORS: COMMANDED POSITION - CMM MEASURED POSITION

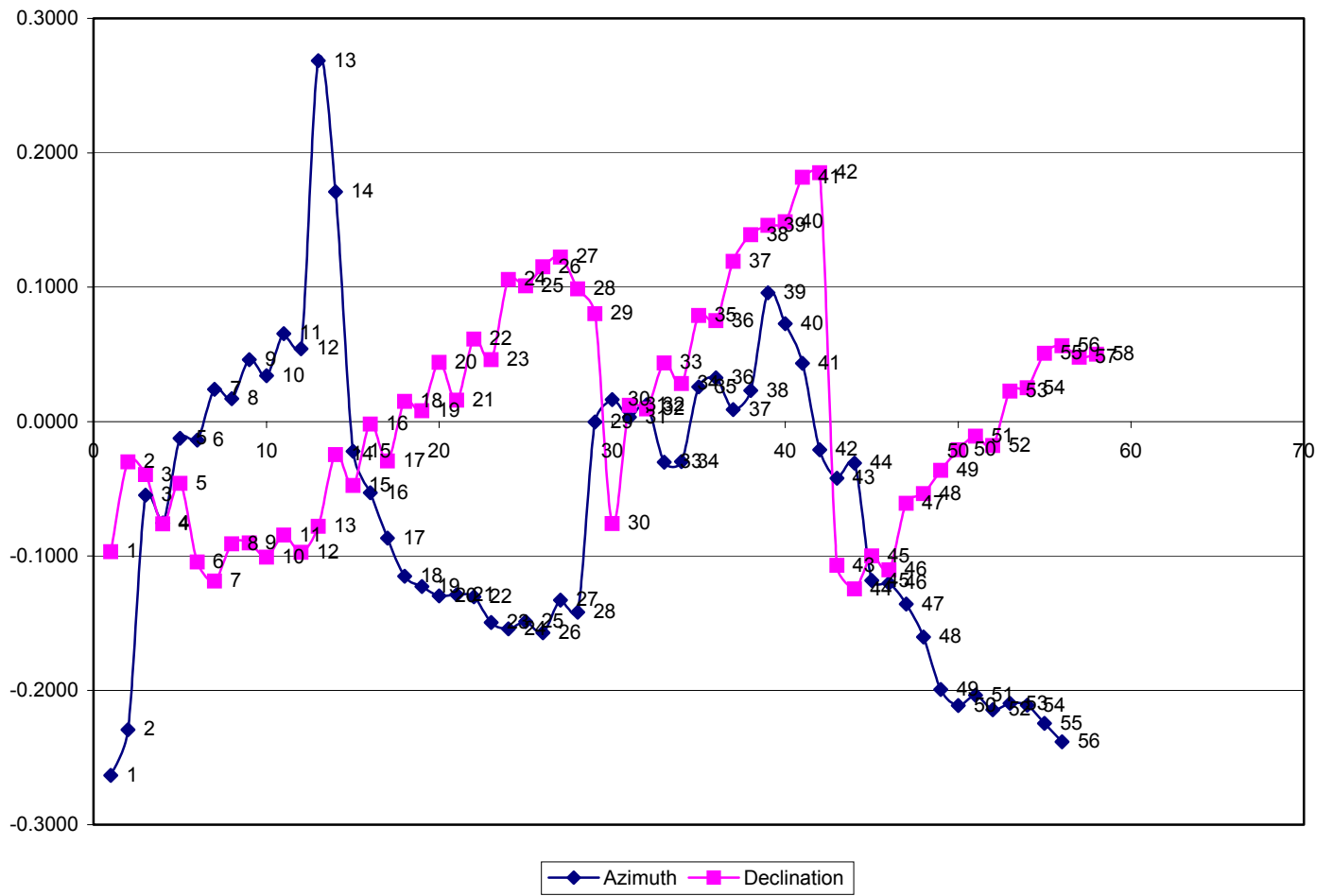**Figure A2: ERRORS; Commanded Position – CMM Measured Position**
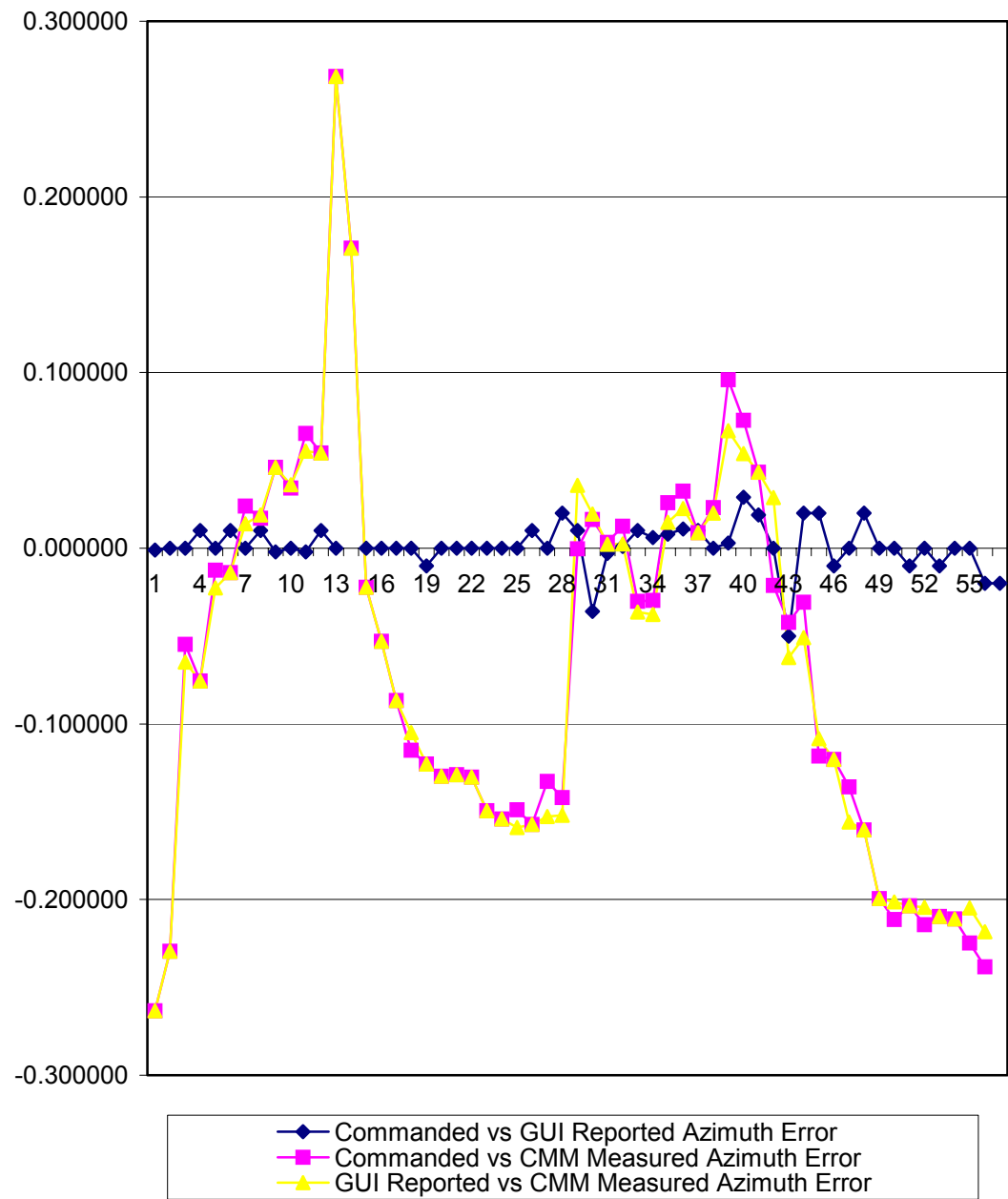
Figure A3: Azimuth Error

Declination Error
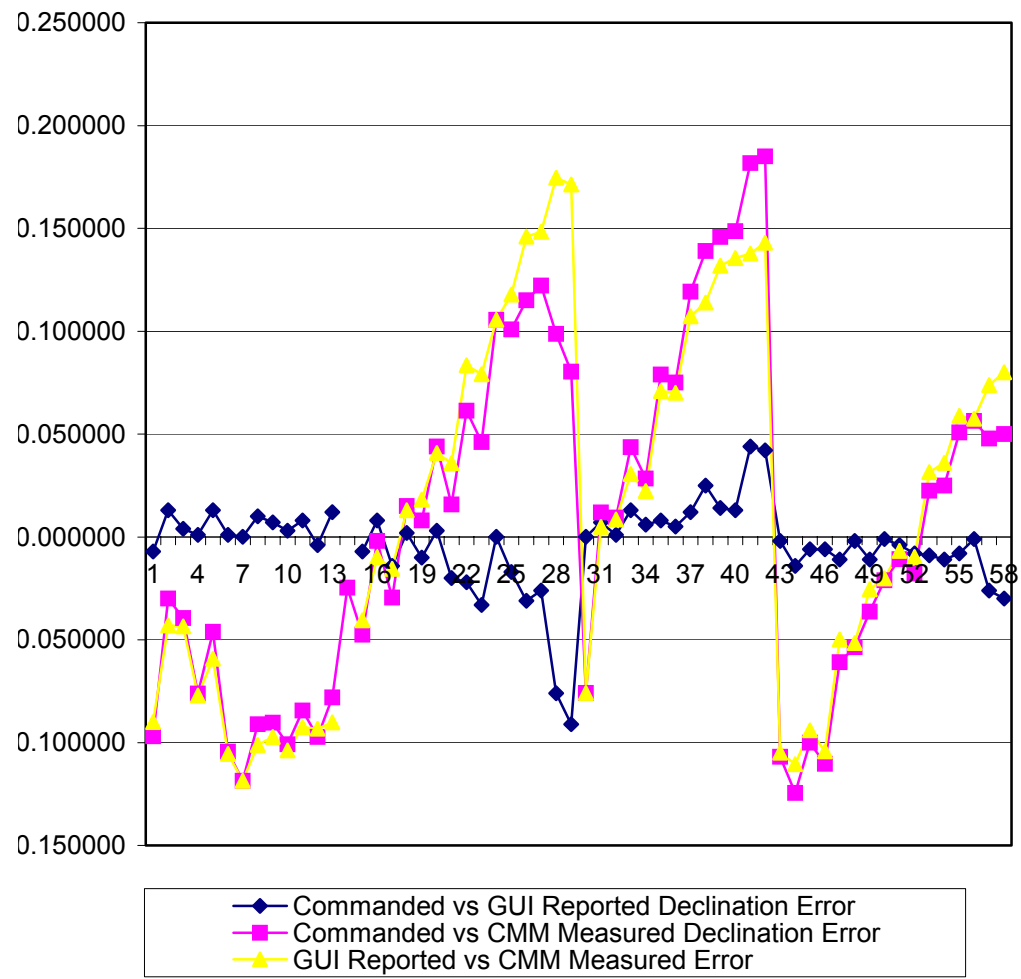
Figure A4: Declination Error
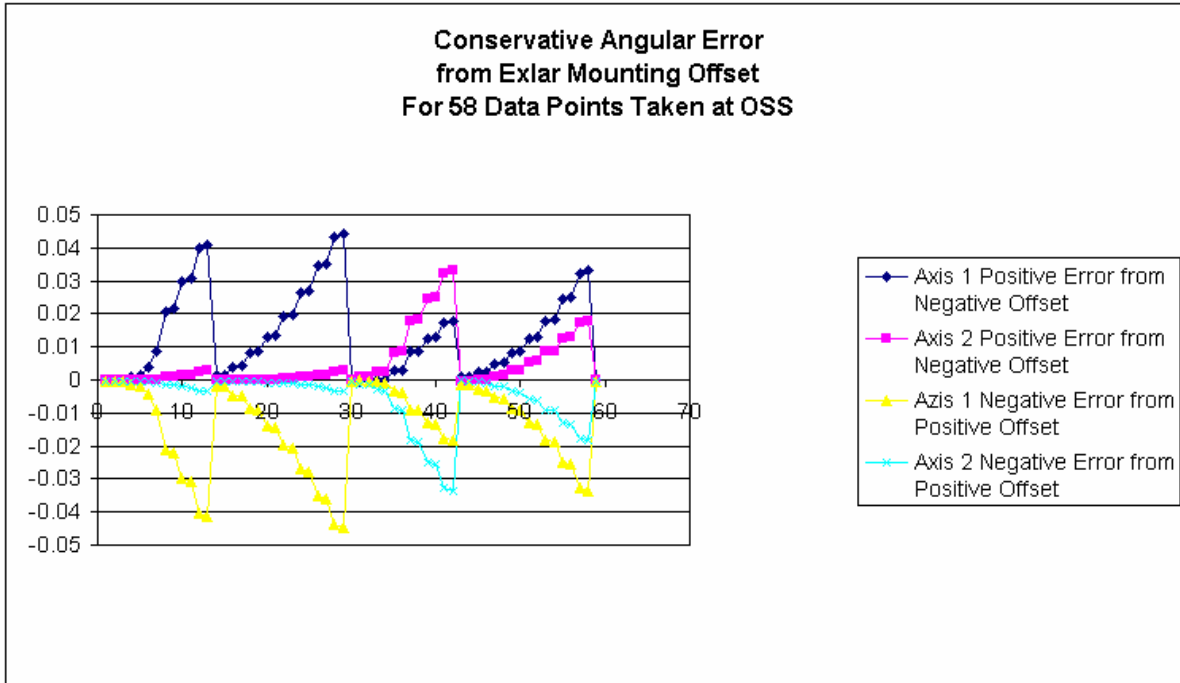
Figure A5: Conservative Angular Error from Exlar Mounting Offset for 58 Data Points Taken as OSS

Finally, similar error measurements for declination angles were determined and are shown in Table IV. Note that errors that exceed 0.06 degrees are greater than the goal set for the Sensor Mount. Following these tests the controller was reconfigured with different PID coefficients to bring the stopping point into tighter control. At the same time the Exlar actuators were remounted on the baseplate to make the movements more symetrical.

Note: Subsequent to these measurements it was determined that high friction/stiction caused by an undersized accuator bushing was causing the motors to heat excessively. This friction/stiction in turn caused the actuators to stop before reaching the commanded positions. The bushings were enlarged after the unit was returned to Ross-Hime Design's office.

After the repositioning of the Exlar actuators the CMM tests were performed again. Table V illustrates the angular error for the two axis. Now the errors on both axis are well within the 0.06 dregree goal set for the Sensor Mount. This result shows the importance of having the actuators positioned correctly on the baseplate.

At this point the Sensor Mount System was returned to Ross-Hime Designs where testing resumed.

Appendix B
Test Procedure at University Technology Center

After the tests were completed at Oceaneering Space Systems, Inc. (OSS) the Omni-Wrist III Sensor Mount (Sensor Mount) was returned to the Ross-Hime Designs office located in the University Technology Center (UTC) for further evaluation. A support for the Sensor Mount had been previously designed and built and now was attached to an outside wall at UTC. This support provided a solid base for the remainder of the testing. Figure B1 shows the support with the Sensor Mount attached. A laser pointer was attached to the Sensor Mount at the center hub. The central hub also incorporates the means to attach various weights. We used regular bell bar weights for the testing. Weights of 4.6 and 6.1 pounds were the primary values used.

Figure B1: Sensor Mount Attached to Support

The detection stage was an adjustable assembly that is shown in Figure. B2. The stage held a paper "target" like the one shown in Figure B3. The rings have 0.1 inch increasing radii which represents about 74.06 arcseconds/0.1" resolution when the Sensor Mount and the

Figure B2: Detection Stage

detector stage were separated by 278.5 inches. This stage was magnetically clamped to one of the steel door jams in the test room. The laser pointer had a diverging beam whose width was approximately 300 arcseconds at the 23 foot separation. During the tests the beam was projected through the paper target and either a mark was made at the center of the beam from the back side of the target or a circle was drawn around the central beam. In this way the centroid of the beam could be accurately found to within 30 - 50 arcseconds or about ±0.5 squares. We found it more
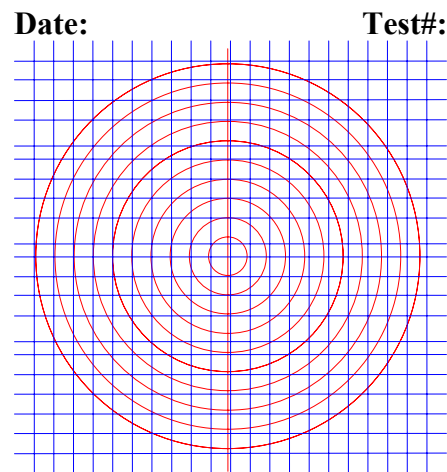
Figure B3: Bullseye Pattern at Detector (0.1 inch feature size)

convenient to measure the position in "number of squares in the X and Y directions. Conversion to arcseconds was performed as a last step. The laser pointer could be attached to the holder in two separate positions. The first position allowed the "home" position to be at Declination 90 degrees and Azimuth 180 degrees. Here the tip of the Sensor Mount was horizontal at the home position. This position also produced full extension of the Exlar actuators. The second position made the "home" position at Declination 0 degrees and Azimuth 0 degrees. This configuration has the Sensor Mount straight up at the home position. The controller hardware is shown in Figure. B4. The controller system includes power supplies, processors, motor controllers and a laptop computer that displays the graphical user interface (GUI).

Figure B4: Sensor Mount Controller

Test Procedure

The typical test procedure consists of 1) centering the beam on the bullseye pattern, 2) translating the Sensor Mount to some "other" position, 3) returning it to the original position and 4) marking the beam center on the bullseye pattern. The "other" positions are small angles, large angles and mixed axis translations. Various weights can also be attached to the Sensor Mount so bending moments and the effects of moving different weights through different angles can be determined. We feel confident that these tests, while simple in nature, give useful information on the "repeatability" of pointing.

Results

After the Sensor Mount was returned from OSS the Exlar actuators were found to have higher than normal friction/stiction. This led to excessive heating in the actuators motors. The problem was traced to the end cap bushings. The bushings were removed and the bushing opening was enlarged by about 0.0002 inches. This provided substantially less friction to the accuator motion. The coefficients for the Proportional Integral Differential (PID) motor control had been determined under the high friction condition. The reduced friction now required the various PID coefficients to be readjusted. The new coefficients were determined and the Sensor Mount was set for operation.

Two additional problems surfaced as the Sensor Mount was put through its "homing" routine. The homing sequence is a requirement for the software to know the exact position of the Sensor Mount. On what appears to be a random basis, as the Sensor Mount was going through the homing routine a unexpected jog of approximately 18 degrees took place. This invalidated the Sensor Mount's position so the homing routine was repeated. We believe this is a software "bug" and will be fixed in the next software iteration. The second problem surfaced when a large excursion of one of the actuators took place. Instead of a smooth motion the accuator seemed to vibrate and caused the Sensor Mount to occasionally "lock up". It seemed most severe at declination near 90 degrees and azimuth near 315 degrees. We replaced the actuators with ones with less pre-load and found the problem was less severe. Exlar Inc. is working on the problem.

The results of an early test are shown in Table BI and a detailed description follows. Here the home position was Dec. 0; Az. 0 (0, 0). The initial laser beam position at the detector stage was determined, (Xi = -2 squares; Yi = 0.5 squares). The Sensor Mount was then moved to (70, 0) and returned to home. The beam position was again measured (X = -3; Y = 2). The entire procedure was then repeated five times. The Sensor Mount was then moved to (70, 180) and returned to home where the laser beam position was determined. This operation was also repeated five times. In like manner the Sensor Mount was moved to (70, 90) and (70, 270). Movement to the four "cardinal" compass points were accomplished without interruption and

Table BI: Test Equence #11 The Four Compass Points

Xi	Yi	Dec	Az	1-X	1-Y	2-X	2-Y	3-X	3-Y	4-X	4-Y	5-X	5-Y	Avg X	Avg Y	Total	
																Avg X	Avg Y
-2	0.5	70	0	-3	2	-3	1	-3	1	-3	1	-3	1	1	-0.7	1.05	1.20
		70	180	-3	-2	-3	-2	-3	-2	-3	-2	-3	-2	-0.60	2.60		
		70	90	-3	-1	-3.2	-1	-3.2	-1	-3.2	-1	-3.2	-1	-0.44	-1.20	77.8	88.9 Arcseconds
		70	270	-3	-0.8	-3	-0.8	-3	-0.8	-3	-0.8	-3	-0.8	-0.80	-0.36		

without additional jogging or a homing sequence. Data for these movements are shown in the Table. The average change of beam position during the five repeat movements is shown in columns labeled Avg X and Avg Y. **For these averages the last beam position of the preceding row becomes the initial position for the row under consideration,** e.g. for the movement to (70, 90) the initial position (Xi, Yi) is (-3, -2) - the last position of the preceding movement to (70, 180).

The average change for all movements during this sequence is shown in the last columns. Finally, a conversion to arcseconds is made. The detailed description of the test procedure is for illustrative purposes and will not be repeated for the description of the other tests.

During these tests the Sensor Mount goes through the several position changes without additional jogging or homing sequences. However, some of the tests had to be aborted because of the accuator problem previously described and a rehoming sequence was required. A new test sequence would then begin.

The results for the in-between directions are shown in Table BII. As the test

Table BII: Test Sequence #18

Xi	Yi	Dec	Az	1-X	1-Y	2-X	2-Y	3-X	3-Y	Avg X	Avg Y	Total	
												Avg X	Avg Y
0	0	89	0	0.5	3.5	0.5	3.5	1	3.5	-0.50	-2.33	0.67	2.00
		89	45	1	3.5	1	3.5	1	3.5	0.33	1.17		
	89	90	1	3.5	1	3.5	1	3.5	0.33	1.17	49.4	148.1 Arcseconds	
		89	135	2	2.5	2	2.5	2	2.5	-0.33	1.83		
		89	180	Abort - Rehome									

proceeded a "glitch" occurred and the Sensor Mount had to be rehomed. For these four points the average variation in X and Y was 49.4 and 148.1 arcseconds. The test sequence continued during Test Sequence #19 and the results are displayed in Table BIII. Note that the repeats now number three instead of five. The reason was to conserve time since all angular directions had to be entered manually into the controller every time a Sensor Mount movement occurs. For these excursions the average variation in the X direction was 0 arcseconds and the average variation in the Y direction was -128.6 arcseconds.

Table BIII: Test Sequence #19

Xi	Yi	Dec	Az	1-X	1-Y	2-X	2-Y	3-X	3-Y	Avg X	Avg Y	Total Avg X	Avg Y	
0	0	89	180	0	0	0	0	0	0	0.00	0.00	0.00	-1.74	
		89	225	0	0	0	0	0	0	0.00	0.00			
		89	270	0	1	0	1	0	1	0.00	-0.67	0.0	-128.6	Arcseconds
		89	315	0	2	0	2	0	2	0.00	-0.33			
		45	0	0	2.5	0	3	0	3	0.00	0.17			
		45	90	0	3	0	3	0	3	0.00	1.00			
		45	45	0	3	0	3	0	3	0.00	1.00			
		45	135	0	2	0	2	0	2	0.00	1.67			
		45	180	0	1	0	1	0	1	0.00	1.33			
		45	225	0	1	0	1	0	1	0.00	0.33			
		45	270	0	2	0	2	0	2	0.00	-0.33			
		45	315	0	3	0	3	0	3	0.00	0.00			

The home position was changed from Dec = 0, Az = 0 to Dec = 89 and Az = 180. We had intended (90, 180) but there were occasional "glitches" that caused the Sensor Mount to rehome. This problem did not occur at (89, 180). At this home position both actuators are fully extended so this should be the worst case position. During this test the average X and Y variation was -77.8 and 200.2 arcseconds, respectively. The Y variation was the only one that came close to the design goal maximum.

Table BIV: Test Squence #15

Xi	Yi	Dec	Az	1-X	1-Y	2-X	2-Y	3-X	3-Y	Avg X	Avg Y	Total Avg X	Avg Y	
0	0	0	0	0	0	0	0	-0.5	0	0.17	0	-1.04	2.70	
		45	90	-0.5	0	-0.5	0	-0.5	-1	-0.17	0.33			
		45	270	0.5	-2	0.5	-2	1	-3	-1.00	0.67	-77.8	200.2	Arcseconds
		45	0	1	-3	1	-3	2	-3	0.00	-1.00			
		75	180	2	-3	2	-4	2	-4	0.67	-0.67			
		75	45	1	-2	1	-3	1	-3	1.33	-2.33			
		80	170	1	-3	1	-3	1	-3	0.33	-1.00			
		89	90	1	-3	1	-3.5	1	-3.5	0.33	-0.83			
		89	270	3	-6	3	-6	3	-6	-1.00	0.50			
		89	315	Abort - Rehome										

Test Sequence #16 proceeded normally until Az = 315 degrees was reached. An abort happened that required a rehoming. Several more rehoming sequences followed as we worked around Az = 315 degrees. At this position the one accuator with the highest preload had to extend fully. Vibrational noise was observed and a rehoming sequence was necessary. We decided to explore around the Az = 315 degrees. The results are shown in Table BVI. The

movement of the Sensor Mount was well behaved as it was pointed closer and closer to Dec = 89, Az = 315. At that extreme angle the system stopped and the Sensor Mount had to be rehomed. Excluding (89, 315), the variations in X and Y were only -65.8 and +65.8.

Table BV: Test Sequence #16

Xi	Yi	Dec	Az	1-X	1-Y	2-X	2-Y	3-X	3-Y	Avg X	Avg Y	Total Avg X	Avg Y	
2	-5.5	45	45	1.5	-5.5	1.5	-6	1.5	-6	1.00	-1.67	-0.46	1.83	
		80	0	2	-7	2.5	-7	2.5	-7.5	0.00	-1.17			
		89	135	2	-6	2	-6	2	-7	1.17	-3.17	-33.9	135.8	Arcseconds
		89	225	4	-10	4	-10	4	-10	-0.67	-0.33			
		89	315	Abort -Rehome										

The next tests involved the home position (0, 0). The Sensor Mount was exercised to (89, 45) then to (89, 225) and back to home (0, 0). This maneuver was repeated fifteen times and the results are shown in Table BVII. Again the average variations in the X and Y positions of the laser beam were measured and found to be -32.1 and -101.2 arcseconds, respectively.

Table BVI: Test Sequence #17

Xi	Yi	Dec	Az	1-X	1-Y	2-X	2-Y	3-X	3-Y	Avg X	Avg Y	Total Avg X	Avg Y	
0	0	15	315	0	0	0	0	0	0	0.00	0.00	-0.89	0.89	
		30	315	1	-1	1	-1	1	-1	-0.67	0.67			
		89	45	1	-1	1	-1	1	-1	0.33	-0.33	-65.8	65.8	Arcseconds
		35	315	1	-1	1	-1	1	-1	0.33	-0.33			
		40	315	1	-1	1	-1	1	-1	0.33	-0.33			
		50	315	1	-1	1	-1	1	-1	0.33	-0.33			
		60	315	1	-1	1	-1	1	-1	0.33	-0.33			
		70	315	1	-1	1	-1	1	-1	0.33	-0.33			
		80	315	1	-1	1	-1	1	-1	0.33	-0.33			
		89	315	Abort - Rehome										

A second repeatability test after multiple moves was conducted. Here the home position was again (0, 0). The Sensor Mount was first moved to Dec = 70 Az = 0 then to Dec 70, Az 180 and then back to home. This sequence was repeated ten times and the X and Y variations were measured. Table BVIII shows the results. The average variation for the ten repeats was X = 130 and Y = -94.2 arcseconds.

Table BVII: Repeatability Test After Compound Move

Xi	Yi	Repeat #	X	Y		Avg X	Avg Y
0	0	1	0	0		-0.41	-1.28
		2	0	0			
		3	-0.5	-0.5		-32.1	-101.2 Arcseconds
		4	-0.5	-1			
		5	-0.5	-1			
		6	-0.5	-1			
		7	-0.5	-1.5			
		8	-0.5	-1.5			
		9	-0.5	-2			
		10	-0.5	-2			
		11	-0.5	-2			
		12	-0.5	-2			
		13	-0.5	-2			
		14	-0.5	-2			
		15	-0.5	-2			

Table BVIII: Repeatability Test After Compound Move

Xi	Yi	Repeat #	X	Y		Avg X	Avg Y
0	0	1	0	-0.9		1.74	-1.26
		2	0	-0.9			
		3	0	-0.9		130.0	-94.2 Arcseconds
		4	1.5	-1.5			
		5	0.7	-1.2			
		6	1.5	-1.5			
		7	2.5	-1.5			
		8	2	-1.2			
		9	4	-1.5			
		10	5.2	-1.5			

The next tests all involved small angle movements. Ten repeats were used and three different angular movements were used, one degree, five degrees and 0.5 degrees. These movements were performed at the two home positions of (0, 0) and (89, 180). The results for the home position (0, 0) and the three positions of (1, 1), (5, 5) and (0.5, 0.5) are displayed in Table BIX.

Table BX shows the results for the home position (89, 180) and the three movements to (1,1), (5, 5) and (0.5, 0.5). The average reproducibility error for all these movements is quite a bit larger than their counterpart at the home position (0, 0).). The reason is that this home position is at the maximum extension of the actuators and the movement of the Sensor Mount is the least certain at this position.

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Table BIX: Small Angle Tests (Home (0, 0))

Xi	Yi	Dec	Az	X-1	Y-1	X-2	Y-2	X-3	Y-3	X-4	Y-4	X-5	Y-5
0	0	1	1	0	0	0	0.5	0	1	0	1	0	0
		5	5	0	0	0	0	0	0	0	0	0	0
		0.5	0.5	0	0	0	0	0	0	0	0	0	0

X-6	Y-6	X-7	Y-7	X-8	Y-8	X-9	Y-9	X-10	Y-10	Avg X	Avg Y	Total Average X	Y
0	0	0	0	0	0	0	0.5	0	0	0	-0.3		
0	0	0	0	0	0	0	0	0	0	0	0	0.00	-0.10
0	0	0	0	0	0	0	0	0	0	0	0		
												0.00	-7.17 Arcseconds

Table BX: Small AngleTests (Home (89, 180)

Xi	Yi	Dec	Az	X-1	Y-1	X-2	Y-2	X-3	Y-3	X-4	Y-4	X-5	Y-5
0	0	88	179	-1	1	-1.5	1	-1.5	1	-1.5	1	-1.5	0
		84	175	-1.5	0.5	-2	0.5	-2	0.5	-2	0	-2	0
		88.5	180	-2	-0.5	-1.5	-2	-1.5	-2	-1.5	-2	-1.5	-2

X-6	Y-6	X-7	Y-7	X-8	Y-8	X-9	Y-9	X-10	Y-10	Avg X	Avg Y	Total Average X	Y
-1.5	0.5	-1.5	0.5	-1.5	0	-1.5	0	-1.5	0	1.45	-0.5	1.53	0.45
-2	0	-2	0	-2	0	-2	0	-2	-0.5	0.45	-0.1		
-1.5	-2	-1	-2	-1	-2.5	-1	-2.5	-1	-2.5	-0.65	1.5	113.4	33.4 Arcseconds

A speed of movement was the final test performed. A stop watch was used to measure the time from start to finish of a 178 degree movement.   We did this measurement during one of the multiple movement experiments shown in Table BVII. The average time was 1.08 seconds or over 160 degrees/second. This result is much higher than the goal of at least 60 degrees/second.

Conclusion

The Sensor Mount was exercised through many different sequences. Two home positions, (0, 0) and (89, 180) were used. A laser pointer was used to shine a light spot on a bullseye target mounted a little over 23 feet from the Sensor Mount. At that distance the position of the laser beam could be determined within about $\pm$ 35 seconds of arc. The test sequences consisted of large angle deflections, small and medium angle deflections, and multiple angle movements. A weight of 4.6 lb. was attached to the Sensor Mount for all except the first test

when a weight of 6.1 lb. was used. For all the tests not one of the tests produced an average repeatability error greater than the goal of 216 seconds of arc, approximately 2.9 squares. With one exception (see Table BV), even within the test sequences individual repeatability tests did not exceed the design goal.

In general the reproducibility error was less at the home position (0, 0). The actuators are retracted here and the Sensor Mount movements are more certain than at the accuator position extremes. Speed tests indicated that an angular deflection greater than 160 degrees/second could be accomplished - much faster than the goal of 60 degrees/second.

Some problems occurred with the actuators that we believe are related to the preloads on these actuators. This problem required an increase in drive current to the actuators to bring them back to operation. In the extreme case the accuator had to be replaced. This is a problem we are working cooperatively with Exlar, Inc. A software problem also surfaced that randomly caused an 18 degree shift in the home position. The only solution with the present software is to reboot and continue the "homing" sequence.